Bulk Density and Moisture Effects on Monte Carlo Simulations of Soil Carbon Analysis for the INS System

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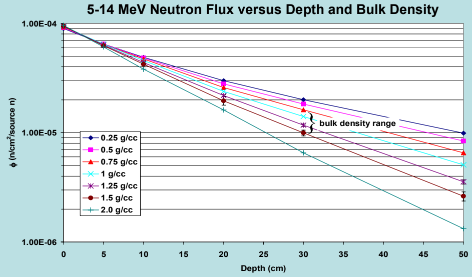
Abstract

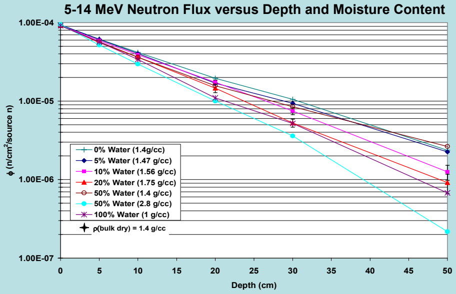
Inelastic neutron scattering (INS) is a new method for carbon analysis in soil, in the field, that is completely non-destructive and uniquely measures large volumes of ~0.3 m^3. It is based on fast 14 MeV neutrons undergoing inelastic neutron scattering with carbon nuclei and inducing the emission of 4.43 MeV gamma rays. The fast neutrons are produced by a (d,t) neutron generator (NG) with the induced gamma rays being detected by an array of NaI detectors. The transport of neutrons and gamma rays in the soil is affected by the bulk density and moisture content. While variations in the bulk density affect both the neutron and the gamma rays' mass attenuation coefficients, the moisture affects mainly the transport of neutrons due to elastic scatterings with hydrogen nuclei. Changes in the transport properties of the soil might affect the carbon signal yield from various depths that would affect the calibration and sampled depth and volume. A probabilistic Monte Carlo method is utilized to model the system. The entire system is simulated, following the paths of particles from their creation to death thus enabling modeling accurately this complex system and economically replacing complicated experiments. The code used here is the Monte Carlo N-Particle transport code Version 5 (MCNP5) developed at Los Alamos National Laboratory. This work assesses the magnitude of the expected change in the carbon signal yield due to variations in the soil parameters; bulk density and moisture content.

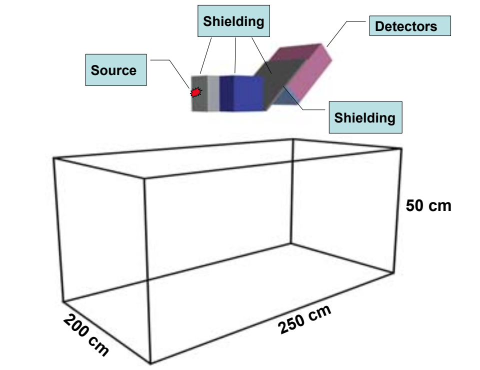
5-14 MeV Neutron Flux versus Depth and Bulk Density



An isotropic 14 MeV neutron point source was modeled to emit into a 250cm by 200cm by 50cm soil volume with a carbon content of 2% by weight. The fast neutron flux, 5-14 MeV, in the soil is plotted versus bulk density and moisture content variations.

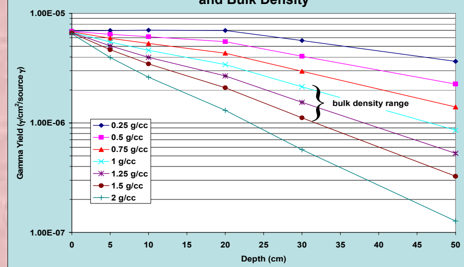
5-14 MeV Neutron Flux versus Depth and Moisture Content





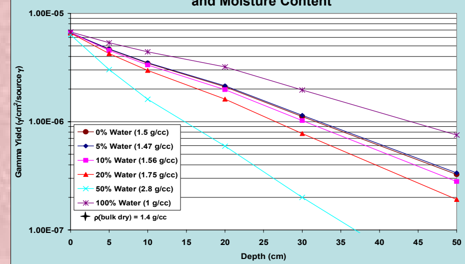
System geometry and soil volume modeled in MCNP5.

4.43 MeV Gamma Ray Yield at the Detectors versus Depth and Bulk Density



An isotropic 4.43 MeV gamma point source was modeled to emit from different depths of a 250cm by 200cm by 50cm soil volume with a carbon content of 2% by weight. The carbon region of interest gamma yield, 4.43 MeV, at the detectors is plotted versus bulk density and moisture content variations.

4.43 MeV Gamma Ray Yield at the Detectors versus Depth and Moisture Content



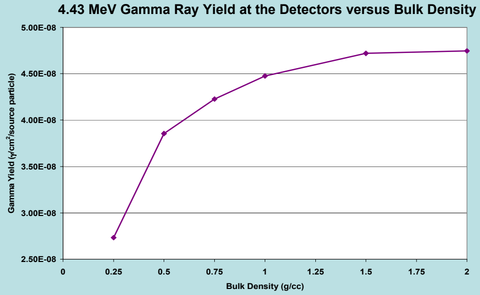
Moisture Content and Bulk Density

The soil bulk density is affected by an increase in moisture content. Assuming that a given soil volume remains constant with the increase of moisture content, i.e. pore space allowing, and no swelling occurs, the increase in the bulk density of the given soil volume is dictated by equation 1.

$$\rho_{B_{new}} = \frac{\rho_{B_{old}}}{1-X} \qquad (1)$$

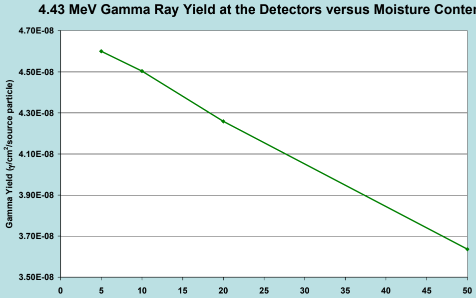
Where: ρ_{Bold} = old bulk density previous to addition of moisture
ρ_{Bnew} = new bulk density with added moisture
X = the weight fraction of moisture added

4.43 MeV Gamma Ray Yield at the Detectors versus Bulk Density



An isotropic 14 MeV neutron point source was modeled to emit into a 250cm by 200cm by 50cm soil volume with a carbon content of 2% by weight. The carbon region of interest gamma yield, 4.43 MeV, at the detectors is plotted versus bulk density and moisture content.

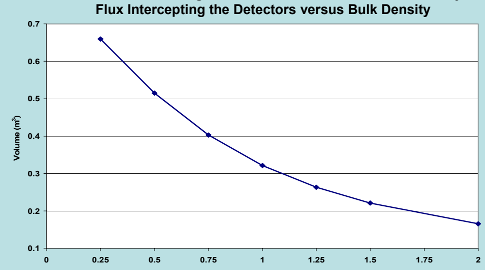
4.43 MeV Gamma Ray Yield at the Detectors versus Moisture Content



Conclusions

- Soil bulk density affects the neutron and gamma transport through soil thus affecting the gamma yield at the detectors. However in the average bulk density range the effect is minimal.
- Moisture content affects the neutron and gamma transport through the increase of bulk density, rather than the increased presence of the hydrogen introduced into the soil volume.
- The 4.43 MeV gamma ray yield at the detectors increases with increasing bulk density, as a result of the increased number density.
- The volumes contributing to 90% of the total carbon gamma ray flux and the maximum depth of these volumes decreases with increasing bulk density. The decrease can be attributed to the increased number density of the elements in the soil, as a larger fraction of the gamma ray yield will come from a more shallow depth.

Volumes contributing to 90% of the Total Carbon Gamma Ray Flux Intercepting the Detectors versus Bulk Density



The volumes contributing to 90% of the total carbon inelastic gamma ray flux intercepting the detectors and the maximum depth associated with the volumes are plotted versus bulk density variations.

Maximum Depth of Volumes contributing to 90% of the Total Carbon Gamma Ray Flux Intercepting the Detectors versus Bulk Density